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FLOODS AND ACCELERATED EROSION IN NORTHERN UTAH

U. S. DEPARTMENT OF AGRICULTURE
MISCELLANEOUS PUBLICATION NO. 196



COVER ILLUSTRATION

An oblique aerial photograph of the area devastated by floods at the mouth of Parrish Creek in 1930. (See text, p.8). At the upper right is Centerville Canyon. Slightly above the middle of the picture the upper level of old Lake Bonneville shows clearly. In the white patch below stands isolated the schoolhouse referred to in the text. Running across the picture just below the schoolhouse is the State highway; lower and parallel, the electric railroad. The area in the vicinity of the schoolhouse was formerly swampy land underlaid with more than 50 feet of fine soil and lacking in characteristic flood material. In 1930, several feet of flood debris, including boulders up to 20 tons in weight, were spread over the area, for the first time in post-Bonneville history.

FLOODS AND ACCELERATED EROSION IN NORTHERN UTAH¹

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INTRODUCTION

The torrential run-off from heavy summer rains in recent years in northern Utah has eroded soil from the slopes and produced violent floods which have channeled deeply both canyon and valley fill. Debris from the canyons has been deposited over agricultural lands in the valleys both by the conventional stream washing of gravels and by mud-rock flows. The frequency of occurrence and the size of peak flows of this run-off, more especially from torrential rains on drainage areas of appreciable gradient, appear to be on the increase (3).² Gregory and Moore (7) have been impressed with apparently recent channeling in previously well aggraded valleys in southern and southeastern Utah. Bryan (2) has reviewed statements and has presented a hypothesis as to the inception and causes of accelerated erosion in parts of the Southwest, including southern Utah. Floods and accelerated erosion are regarded as a problem of growing concern in many sections.

However, owing chiefly to the lack of sufficient concrete scientific evidence, the assumption that surface run-off of flood proportions

¹ The studies reported in this publication were conducted by the Intermountain Forest and Range Experiment Station in cooperation with the geology department and the agricultural experiment station of the Utah State Agricultural College. The division of responsibility and coordination of activities were as follows: The general direction of the study was handled by Mr. Forsling in cooperation with P. V. Cardon, director of the Utah State Agricultural Experiment Station. Professor Bailey is responsible for the geological observations and prepared the section of the report dealing chiefly therewith. Mr. Forsling and Professor Becraft are responsible for the vegetational observations and prepared the section of this report dealing with them. The field work and the preparation of the report were for the most part carried on jointly.

² Italic figures in parentheses refer to Literature Cited, p. 21.

and erosion have increased materially in frequency and intensity in recent years is a moot question. Further, where such increases are admitted, there is considerable debate as to their cause. Unquestionably, economic damage is being done by floods and erosion, but the one essential in any attempt to halt this damage is the determination of the degree of abnormalcy of accelerated run-off and erosion and their causes. The recent floods in northern Utah present an unusual opportunity for just such an analysis, since here certain geologic observations may be made, such as are not possible in most localities, presenting a remarkably complete and convincing history of erosion and flood phenomena stretching back over many centuries.

The purpose of this publication is to present this geologic evidence and to point out the apparently unavoidable conclusion that these recent floods in northern Utah constitute abnormal run-off and accelerated erosion and thereby mark a radical change from the normal rate of gradation of the present geologic epoch and climate. The authors will also present evidence tending to show that this condition is attributable chiefly to the depletion of the plant cover on the watersheds of the drainages involved.

RECENT UTAH FLOODS AND THEIR GEOLOGIC BACKGROUND

Destructive floods, the first of real consequence since the coming of settlers in 1847, occurred along the west slope of the Wasatch Mountains in Utah in the summer of 1923 and again four times in 1930 (1, 3, 5, 8). The most damaging of these were along the narrow alluvial plain in the Centerville-Farmington section, which lies in the basin of extinct Lake Bonneville (6) between Salt Lake City and Ogden, the most intensively cultivated and densely populated rural section in Utah. Floods and mud-rock flows came down four of the canyons in the section—Ford, Davis, Steed, and Farmington—on August 13, 1923. On July 10, 1930, similar floods came down each of these canyons and also down Parrish Canyon (figs. 1 and 2). Resultant damages included the demolition of several houses; the surfacing of many acres of garden and farm lands with mud and rock, including boulders weighing individually up to 300 tons; the blocking of the State highways and an electric railroad; and, in 1923, the loss of several lives.

The canyons that were flooded are short and steep, having their origin on the west slope of the mountain at an elevation of about 9,000 feet and descending in a distance of 4 miles to the valley floor 4,300 feet above sea level. Each drainage area is small and independent, free from the complexities of larger stream systems. The valley lands at the base of the mountain constitute but a narrow strip, varying in width from 2 to 4 miles, bordered on the west by Great Salt Lake. They are made up principally of lake deposits laid down when ancient Lake Bonneville occupied that locality, and are superimposed on alluvial fans formed prior to Lake Bonneville. These ancient fans have greatly influenced the topography and in places are exposed. From the mountain front the deltas descend in step-like profile to the broader strip of lake-bottom deposits. Deposits subsequent to the disappearance of Lake Bonneville are of very small area in comparison with the earlier deposits and consist of fans spread on the lower deltas and the old lake bottom.



FIGURE 1.—The flood deposit at the mouth of Parrish Canyon, a typical area in northern Utah devastated by the floods of 1930. Farm buildings were demolished, many acres of garden, orchard, and farm lands were surfaced with mud and rocks, and the State highway and electric railroad were blocked for several days on four occasions. One wall of the schoolhouse (in the center background) was broken in.

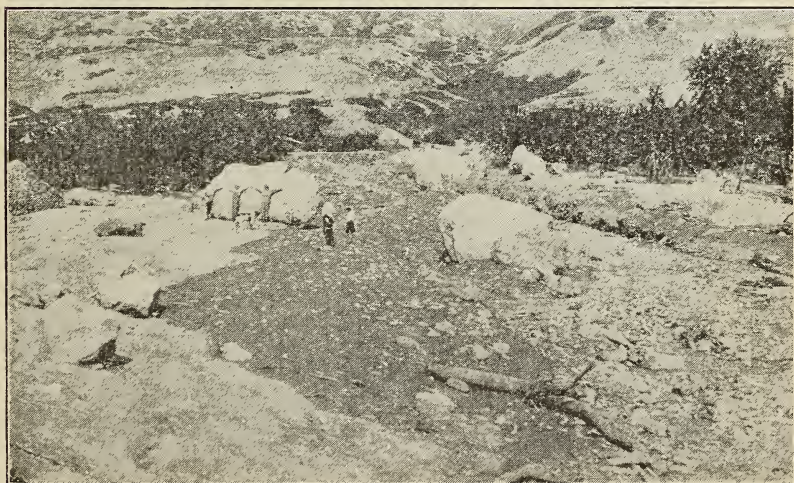


FIGURE 2.—Boulders deposited by the floods of 1930 at the mouth of Parrish Canyon. The force of the floods was shown by their ability to move large boulders, the two largest of which were computed to weigh 150 and 210 tons, respectively, and were transported down a 4-degree gradient a distance about 1,000 feet from the mouth of the canyon. The largest boulder observed to have been moved by any of the floods was one at the mouth of Davis Canyon weighing 300 tons.

The existence during the Pleistocene epoch of Lake Bonneville, in the valley into which drain the canyons that were recently flooded, is of particular significance in this analysis. The greatest expanse of Lake Bonneville is marked not only by deltas but also by a distinct terrace, in some places alluvial and in others wave cut. This is at an elevation of approximately 5,200 feet in Davis County, whereas the mean level of Great Salt Lake, the remnant of Lake Bonneville, is about 4,205 feet above sea level (fig. 3). During this total recession of about 1,000 feet, halts were made at different levels for a sufficient time to permit the formation of distinct deltas; the more prominent of these are the Provo level (elevation approximately 4,825 feet) and the Stansbury level (elevation approximately 4,500 feet). The lowering of the lake from the level of any given terrace gradually exposed a fresh delta front, in which each stream excavated for itself a new channel. The materials thus eroded contributed to the formation of the next lower delta.

In this manner there was formed at the mouth of each canyon a series of deltas, their size and prominence depending largely on the amount of material supplied by the stream. As each delta was exposed by the progressive drying up of the lake, the stream which constructed it became an agent of destruction. Materials eroded since the time of Lake Bonneville have been spread out in front at the lower levels as alluvial fans and bear no marks of deposition in still water. It is estimated by geologists and others that it is no less than 20,000 years since Lake Bonneville receded from the Stansbury level to approximately the present Great Salt Lake. It is at once apparent that the deltas, with their distinct profiles, other lacustrine deposits, and subsequent alluvial debris provide a basis for segregating the deposits according to the time of their construction: Namely, whether pre-Bonneville (made prior to the presence of Lake Bonneville), Bonneville (laid down during the existence of the lake), or post-Bonneville (made since the lake receded). These time divisions are an essential point in determining the erosional history. Such segregation of erosional activity into time periods is not possible in other regions or localities where the single process of alluvial-fan construction has continued without interruption through the ages.

EVIDENCE POINTING TO RECENT ACCELERATION OF FLOODS AND EROSION

The several features which make it possible to date and measure the magnitude of the very recent floods and erosion in comparison with the normal run-off and erosion of the locality are as follows: (1) The fixing of the origin of certain old boulder material along the margins of the trenches formed by the streams in the Bonneville materials; (2) new channeling in delta materials; (3) character and size of post-Bonneville alluvial fans in relation to character and size of materials deposited upon them by the recent floods; (4) the character of fresh excavation in canyon fill; and (5) comparison with erosion deposits of nearby streams having watersheds naturally barren of vegetation.

OLD BOULDER MATERIAL

Ford Creek (fig. 3) is typical of the locality, having well-developed deltas. The upper or Bonneville terrace at an elevation of 5,200 feet and the Provo terrace 375 feet below are narrow, and because of the steepness of the mountain front the stream is deeply entrenched in them. Below the Provo level the stream channel bifurcates, and the



FIGURE 3.—Oblique aerial view of the area flooded in 1930 at the mouth of Ford Canyon: *a*, The upper level of ancient Lake Bonneville; *b*, Provo level of Lake Bonneville; *c*, Death Hollow; *d*, State highway; *e*, electric railroad. The lighter portion in the middle foreground shows the area covered by the mud-rock flow.

two channels are cut into the more closely grouped lower deltas. Here the gradient is much less. The older of these two channels, known locally as Death Hollow, has long been abandoned by Ford Creek. It is a shallow channel extending westward down the middle of the deltas. The present channel is much deeper and turns abruptly to the north and then westerly again.

A conspicuous feature of the topography of Ford Creek for some distance below the Bonneville level is ridges, chiefly of boulder material, which are restricted in distribution to the upper margins of the old Death Hollow channel and of the single channel above. They do not occur along the borders of the present channel below the apex with Death Hollow. The ridges, then, form almost continuous deposits extending from the Bonneville delta on down to the mouth of Death Hollow. One hypothesis is that these boulder ridges are evidence of post-Bonneville floods; if this hypothesis were true, it would support the supposition that the recent floods are only a normal recurrence of periodic flooding. Critical study does not, however, support this hypothesis.

The boulder ridges slope gently down the top of the deltas and more steeply down the terraced delta fronts—in other words they conform accurately throughout to the steplike profile of the deltas and therefore must be a part of the delta structure. Hence, if of post-Bonneville construction, the boulder deposits must have been laid down by a single flood or mudflow of a size that would have completely filled the stream channel and have overflowed the banks sufficiently to have left the boulder ridges the entire distance from the Bonneville level to the mouth of Death Hollow. That, however, seems entirely outside the realm of possibility. Above Death Hollow on the steeper face, the channel, which was cut as the ancient lake receded, reaches a depth of more than 150 feet. Death Hollow is less than 15 feet in depth and is narrower and much less steep than the channel above. Consequently, had there occurred a flood of sufficient magnitude to fill and overflow the deep channel on the steep gradient it would have been of such gigantic size that on reaching Death Hollow it would have completely obliterated the channel as well as the deltas in its path. Yet the ridges along Death Hollow remain and are similar in location to those along the upper channel, which points to a common origin. Since they could not have been formed after the streams had channeled the deltas, they must have been formed at some other time. The most plausible explanation is that they constitute the remnants of deposits brought down by flood action at the time the lake stood at the levels of the respective deltas. Then as the lake receded the streams cut through the deposits, leaving remnants as boulder ridges. This suggests the occurrence of floods during the Bonneville period but cannot logically be assigned to floods of the post-Bonneville period.

The deltas of Davis Creek present a picture similar to Ford Creek. The boulder ridges along the high banks of this stream channel have even a more pronounced conformity to the delta profile than those at Ford Creek. Here again there is no evidence of a tendency for the boulder deposits to obliterate the terraces or faces of the deltas; rather, as at Ford Creek, they emphasize these features. These boulder deposits also can best be explained as having a combined stream and lake origin, rather than as having been laid down by floods after the lake reached its present level.

Just north of Davis Creek is another group of conspicuous boulders on both sides of the highway, which have been referred to as evidence of repeated flooding in post-Bonneville time. However, because of their position they could not have been brought through

the present stream channel. They are resting on a slope which extends back to the base of a pronounced deltal front, in which no stream channel has been cut. These boulders are actually part of the pre-Bonneville fan.

NEW CHANNELING IN DELTAS

The present channel through the lower deltas of Ford Creek is much deeper than Death Hollow, but the process of cutting was arrested centuries ago because the gravels and sands forming the sides had long since reached their angle of repose. Both the channel bottom and the sides were covered with a dense growth of trees and shrubs, and a humus-stained soil layer over a foot in thickness



FIGURE 4.—The mouth of Centerville Canyon, a typical uneroded channel. The bottom of the canyon is densely covered with vegetation, and the small stream is hidden from view. This watershed is well covered with plants, and the heavy rain did not cause a flood in this canyon. Adjacent flooded canyons formerly had similar bottoms.

had been formed, indicating that previous to the 1923 flood this channel had been similar to nearby uneroded channels such as that shown in figure 4. The relative stability which it had maintained so long was suddenly ended when this flood ripped out the channel surfacing and cut further into the delta materials. Together the floods of 1923 and 1930 in places cut to a new depth of 40 feet in previously undisturbed Bonneville sands and gravels (fig. 5), an achievement practically equivalent to the total cutting in the thousands of years during which the channel had previously been occupied. Each recent flood cut a gorge with nearly vertical sides which at once started caving and sliding, the rate increasing rapidly as the remnants of channel surfacing were dislodged. Fresh banks have thus been exposed to a height of more than a hundred feet. Similar new cutting took place in the channels of Davis and Parrish Creeks.

ALLUVIAL DEPOSITS

The post-Bonneville alluvial fan at Ford Creek is surprisingly small in mass and extent. A United States Geological Survey map with a 5-foot contour interval (1926) shows little fill beyond the mouth of the present channel, and this fill contains no conspicuously large boulders. The four floods of 1930 together added a total deposit some 12 feet in thickness at the State highway, which is located one-third of the way down the present fan, and spread material far beyond the periphery of any previous fan (fig. 3).

Many boulders weighing upward of 10 tons were deposited on the State highway. A quarter of a mile below, the Bamberger Electric Railroad, constructed originally on swamp land, received a deposit of debris 6 feet deep that included boulders up to 5 feet in

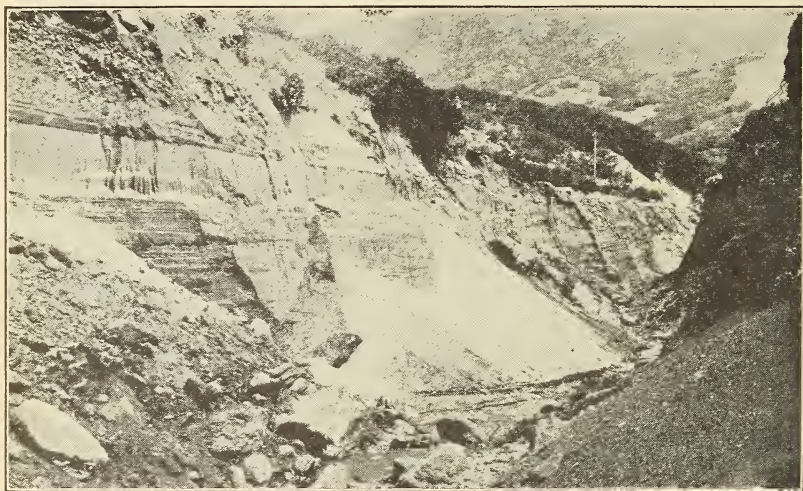


FIGURE 5.—New cutting in the stream channel in the delta of Ford Creek. The floods of 1923 and 1930 in places cut to a new depth of 40 feet in previously undisturbed sands and gravels laid down in the water of Lake Bonneville. The newly exposed strata of assorted sands and gravels, including talus from postflood caving, are shown in the middle section of the photograph.

diameter. If a quantity of flood material practically equal to that of 1930 had been superimposed at intervals of once to several times each century during the thousands of years of the post-Bonneville epoch, there would now be found large alluvial structures extending far out into the present lake. The amount and size of materials brought down by the recent floods are out of all proportion to the rate of previous post-Bonneville deposition.

Parrish Creek supplies additional evidence. Here both the Bonneville and the post-Bonneville deposits are conspicuously small. The very narrow deltas and the small alluvial fan extend out only about 1,500 feet from the mouth of the canyon, where they meet the beds of the lake floor. The bottom land on which a schoolhouse stands was formerly a swamp through which Parrish Creek meandered. (See cover illustration.) Upon being drained it became highly productive land used, until the 1930 floods, for nurseries and truck gardens.

Records of wells drilled on the area show a depth of over 50 feet of fine material with no coarse gravels or boulders characteristic of mountain-flood deposits. On this area the 1930 floods destroyed houses, broke in the east wall of the schoolhouse, and deposited debris to a depth of several feet, including boulders of all sizes up to 20 tons in weight. Some larger boulders were moved about 1,000 feet from the canyon's mouth down a 4° gradient. Several of these weigh from 75 to 100 tons each, and two, previously mentioned, weigh 150 and 210 tons, respectively (fig. 2).

FRESH EXCAVATIONS IN CANYON FILL

The deep gorges freshly excavated for the full length of the flooded canyons are no less impressive than the flood depositions in the valley. Cuts were made in typical canyon fill—in places to a depth of 70 feet. Long, continuous stretches of bedrock were exposed on the bottom of the channels. The canyon fill consisted of debris brought from farther upstream by running water and of materials collected from the adjacent canyon slopes. Included were boulders ranging up to 50 feet in diameter. This fill evidently had accumulated during past centuries following the change in climate which, with the drying up of Lake Bonneville, so reduced the size of the streams that they were no longer able to keep their channels clear. Upon this fill, 70 or more feet deep, the present streams had long since become stabilized, and the canyon bottoms had become densely overgrown with trees, shrubs, and smaller vegetation. These conditions had remained unchanged for an indefinite period until the floods of 1923 and 1930 cut deeply into the fill and carried a large part of the loosened material to the valley below. In places talus slopes, continuous from the ledges above the bottom of the new cut, were disturbed for the first time since they accumulated.

A tributary of Ford Creek gathered waters and earth materials from the first steep slope near the summit of the mountain and within a quarter mile of the summit cut a channel 25 feet deep and equally wide in the gentler slopes of a small basin (fig. 6). The exposure in this cut is largely fine-soil material, with a deep humus-bearing horizon at the top, which represents stability of the surface for centuries back. The absence of erosional unconformities in the fill, as exposed in the cut, shows that the soil had not previously been greatly disturbed. These cuts or scars on the slopes will remain for a long time as testimony to the recent floods. Had important floods occurred frequently during the past several centuries, remnants of the old gullies more or less reclothed with vegetation would be in evidence. No remnants of such gullies were found.

EROSION ON NATURALLY BARREN WATERSHEDS

In contrast to the Farmington-Centerville section is an area about 30 miles to the north along the same mountain front. Here the floods and erosion of recent years are evidently but normal periodic recurrences, and their frequency has been determined by the occurrence of torrential storms. Several smaller canyons in this area between North Ogden and Willard Canyons have built up comparatively large sized, regularly shaped cones of boulder material which

completely cover those parts of the Bonneville deposits upon which they rest. Between the cones, the well-developed terraces are preserved, and the Bonneville terrace is especially conspicuous on the mountain front above. Had floods been normal periodic occurrences in the canyons of the Farmington-Centerville section, it is reasonable to expect that they would also have had large-sized, regularly shaped cones, imposed upon the Bonneville deltas and terraces. The watersheds between Willard and North Ogden are steep and consist almost entirely of bare surfaces of quartzite, slates, and schists. Soil and vegetation occur in but a few places and have played little or no part in regulating run-off from heavy storms. Talus continues to accumulate in the channels until it is swept out by the run-off from a tor-



FIGURE 6.—A channel cut by the floods of 1923 and 1930 in the deep soil in a small basin near the head of Ford Creek, looking downstream. Water gathered on the steeper slopes above and within a quarter of a mile of the summit cut this channel to a depth of 25 feet in previously undisturbed soil. The absence of a humus-stained soil horizon except at the surface indicates that formerly there had been a long period of stability.

rential storm. In these canyons, erosion and transportation of rock waste still keeps pace with weathering, and floods are a normal occurrence.

CONCLUSION BASED ON GEOLOGIC EVIDENCE

It is concluded upon the foregoing geologic evidence that the 1923 and 1930 floods mark a radical departure from the normal post-Bonneville erosion and sedimentation in the canyons of the Farmington-Centerville district. In depth of cutting, in quantity of material, and in size of boulders carried, these floods exceed any others that have taken place in this locality since the recession of Lake Bonneville. The alluvial deposits made since the time of Lake Bonneville are small, and the quantity of material brought from the

canyons and added to them by the recent floods is all out of proportion to the amount brought down through the previous thousands of years of post-Bonneville history.

EVIDENCE POINTING TO CAUSES OF RECENT FLOODS AND ACCELERATED EROSION

To ascertain the conditions producing this accelerated erosion the investigator must look to the watersheds. The relief as already described is steep. The side slopes of the little branched canyons range in gradient up to about 35°. Basins in the heads of the drainages are less steep, in some places having gradients of only 4° to 10°. Such slopes, in the absence of vegetation or other retarding material on the surface, are conducive to rapid run-off of heavy rainfall and erosion sufficient to keep pace with the weathering of the granite gneiss bedrock. However, the watershed of each canyon normally is largely covered to a fair depth with rocky, sandy loam, having a readily noticeable content of organic matter in the upper strata and a layer of litter of dead plant material on the surface. The drainages on the whole are quite heavily vegetated except on some small areas where there has been recent depletion. That slopes, soil, and vegetation had been in reasonable equilibrium for a long period prior to the recent acceleration of erosion on parts of the watersheds, is quite evident.

The three most plausible among the possible causes of the recent accelerated erosion and floods would doubtless be conceded to be diastrophism, as it might influence the gradient of the stream; climatic change, involving greater or more intensive rainfall; and destruction of the plant cover, with concomitant losses of surface litter, reduction of humus content, modification of the physical properties of the surface soil, and a consequent increase in run-off and decrease in moisture absorption on the watershed.

Geologic investigation shows no deformation of the earth's crust sufficient to cause a modification in the gradient of the streams and thereby to account for the recent accelerated erosion.

RAINFALL

Torrential rainfall produced the run-off which accumulated to form the floods of 1923 and 1930.³ There are no rain gages on these watersheds, but the valley and foothill records afforded suggestive information as to the quantity and character of the rain which occurred in connection with the floods. The heaviest rainfall in any 24-hour period recorded in the general locality of the watersheds during the storms of flood was 1.72 inches at Ogden. The highest recorded at some of the other stations was 1.03 to 1.54 inches. Records of rate of rainfall in the general vicinity are available for Salt Lake City and for a portion of the time for the High Line station on City Creek. During the storm of August 13, 1923, at Salt Lake City, 0.35 inch fell in 5 minutes, 0.56 inch in 10 minutes,

³ What is generally considered for the Utah area to be torrential rainfall may be much less, both as to quantity and rate of fall, than is considered torrential in some other climates. The term is used in a relative sense to distinguish between the more common and the heavier rates of fall in the area under consideration.

0.76 inch fell in 15 minutes, 1.05 inches in 30 minutes, 1.17 inches in 1 hour, and 1.23 inches in 2 hours. On this same date at High Line, 0.33 inch fell in 5 minutes, 0.44 inch in 10 minutes, 0.62 inch in 15 minutes, 0.90 inch in 30 minutes, 1.01 inches in 1 hour, and 1.15 inches in 2 hours.

It is considered that the rains which caused the floods in the Centerville-Farmington section did not materially exceed the heavier or more intensive storms which have been recorded at the adjacent valley stations. The run-off from torrential rains leaves its evidence at least on slopes with soils and plant cover of the character here under consideration, which subsequently may be observed. Such rain falling on bare or sparsely vegetated slopes quickly gathers into rills which erode gullies. The size of the gullies, other things being equal, bears a fairly close relationship to the quantity and rate of rainfall. Comparisons after the storms of the amount of fresh gullying on the higher mountain slopes with that on foothill and lower mountain slope areas nearest rain gages, indicated that the gullying on the mountains was not noticeably heavier under comparable conditions than that near the valley stations.

That the quantity and rate of rainfall in these storms of 1923 and 1930 were so excessive as to have been unprecedented on these areas since the date of settlement is not indicated by the records at the four stations near the eastern edge of the Great Basin having continuous-record rain gages. Actual measurements of run-off at the Alpine (Great Basin) branch station (4) show that summer rainfall totaling 0.38 inch or more in an hour, with an intensity of 0.20 inch or more in a 5-minute interval, will result in run-off of flood proportions on a watershed having an average slope of about 10° and a plant cover occupying an average of 16 percent of the surface of the ground. Such rainfall has occurred 4 times in the last 12 years at that station, 5 times in 36 years at Salt Lake City, at least 6 times in 29 years at Modena, and 3 times in 16 years at High Line.⁴

Rains practically equal to the severest one which has occurred in the last 26 years at Salt Lake City, and far heavier than the heaviest recorded at the High Line or Alpine stations in the past 16 years and 12 years, respectively, occurred twice at Modena in the 29 years previous to 1931. Even though the storms of 1923 and 1930 on the watersheds in the Centerville-Farmington section had equalled the two more extreme ones at Salt Lake City and Modena, the records at these two stations indicate an expected frequency of one such storm in every 14 to 18 years. Furthermore, the fact that storms which caused the floods in the Centerville-Farmington section occurred once in 1923 and four times in 1930 in itself indicates a fairly high frequency for such storms. It seems inconceivable that storms of similar or greater intensity than those which caused the floods or which have been recorded during the approximately 35 years since continuous-record rain gages were established at the several stations in Utah have not been equalled or exceeded many times during the

⁴ The Alpine branch station gage is situated at a 10,000-foot elevation on the summit of the Wasatch Plateau in central Utah about 120 miles south of Salt Lake City; the High Line gage is situated in City Creek Canyon at a 5,300-foot elevation on the west slope of the Wasatch Range, about 7 miles northeast of Salt Lake City; the Salt Lake City gage is situated at an elevation of 4,408 feet at the foot of the west slope of the Wasatch Mountains in Great Salt Lake Valley; and the Modena gage is situated at an elevation of 5,479 feet on the Escalante Desert plains about 240 miles southwest of Salt Lake City.

post-Bonneville period—generally considered to be not less than approximately 20,000 years. The recent floods and unprecedented erosion evidenced by the geologic data must be accounted for in some other way.

INADEQUACY OF PLANT COVER

The west slope of the Wasatch Mountain range in the Centerville-Farmington section is, in the main, well covered with vegetation except on localized areas. These are chiefly along the lower mountain front, and on the upper slopes and in the basins at the heads of the canyons which were flooded, where the plant cover has been more or less depleted since the settlement of the section. The intermediate mountain slopes for the most part are well covered with a relatively dense stand of brush.

The lower slopes of the faceted spur mountain ridges between the principal canyons now support a thin stand of plants consisting chiefly of downy chess (*Bromus tectorum*), annual and short-lived perennial weeds, and scattered clumps of oak brush (*Quercus gambelii*). This condition can be noted in the lighter colored part of the slope making up the mountain face below the upper level of Lake Bonneville (fig. 3, a). Judging from a few preserved or restored remnants that are in nearly the original condition—such as in cemeteries and field borders within the general region (9) and on the ungrazed sections of City Creek and the Fort Douglas Military Reservation in the foothills near Salt Lake City—the former cover consisted of a fairly dense stand of bunch grasses, interspersed with sagebrush (*Artemisia tridentata*) and more or less scattered patches of oak brush and other shrubs. The cover on the lower mountain front was heavily depleted by overgrazing and repeated fires many years ago and has been replaced by the present thin stand of vegetation which has continued to be heavily grazed and, at intervals, burned over.

Torrential superficial run-off on slopes having sandy loam soils such as those on the mountain slopes in the Centerville-Farmington section, leaves its telltale marks of gullies and sheet erosion and disturbance of the surface litter to be observed for several months or years thereafter. The presence of numerous gullies on a slope is unmistakable evidence of torrential run-off. The absence of gullies shows that run-off was slight and neither torrential nor rapid. If dead leaves and other light material on the surface of the ground are little disturbed it indicates that run-off was so slight and so slow as not to disturb this lightweight material or that run-off occurred only as slow seepage underneath the litter. It is obvious that a run-off too slight and too slow to disturb plant litter materially would not produce a sudden high head of water of relatively short duration, such as characterized the floods in the canyons in the Centerville-Farmington section.

When these criteria are applied, it is evident that several miniature floods which cut numerous gullies formed on the sparsely vegetated areas of these lower mountain slopes. These small floods, however, did not contribute to the main floods, since the run-off did not empty into the main canyons, but flowed out over the old lake terraces between the canyons, where small alluvial fans were deposited. On the

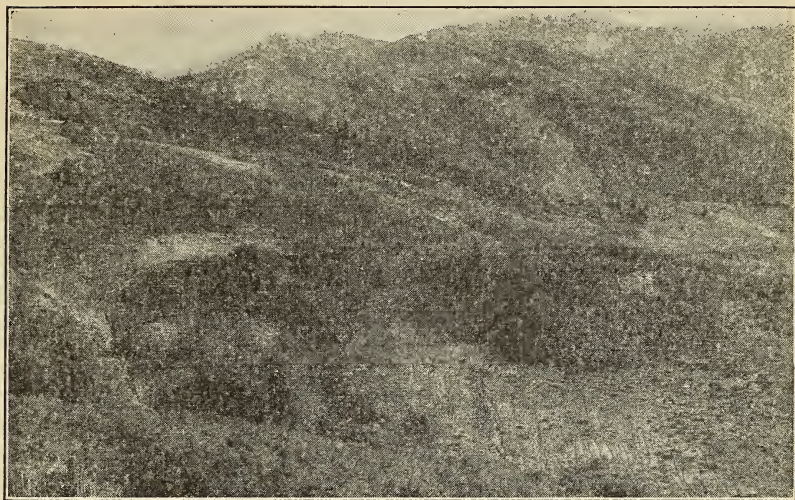
other hand, no concentrated run-off or erosion occurred on the well-vegetated but otherwise similar slopes in the ungrazed foothills of City Creek and the Fort Douglas Military Reservation, although it was evident that the rainfall was equally heavy in both the flooded and nonflooded localities.

ORIGIN OF FLOODS ON DEPLETED AREAS AT HEADS OF CANYONS

The vegetation in the heads of the canyons above the oak zone is variable both as to kind and quantity. A conspicuous feature is the presence of areas, varying in size from less than an acre up to 30 to 40 acres, that have been practically denuded of vegetation, plant litter, and mellow topsoil (figs. 7 and 8). Areas with a fairly dense cover of snowbrush (*Ceanothus velutinus*) and thickets of scrubby aspen (*Populus tremuloides aurea*), having considerable litter and a deep humus soil, constitute the other extreme. Between these extremes are open stands of shrubs, including principally sagebrush, chokecherry (*Prunus melanocarpa*), snowberry (*Symphoricarpos oreophilus*), and aspen. The vegetation increases in quantity more or less progressively outward from the heavily depleted places until eventually a dense cover is reached.

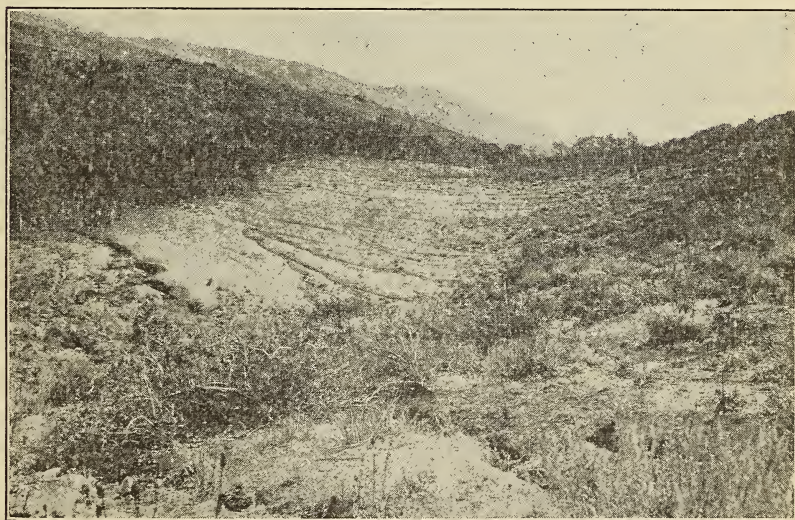
The more gently sloping parts of the stream bottoms and the benchlike features of the head of Ford Canyon, which have a gradient of 4° to 10°, except where strips or portions of the irregularly shaped patches of aspen extend to them from adjacent steeper slopes, are the most heavily devegetated. Practically the only vegetation in these openings in the summer of 1930 consisted of occasional stubby remains of shrubs, including elderberry (*Sambucus microbotrys*), snowberry, and willows (*Salix* spp.), a thin stand of coneflower (*Rudbeckia occidentalis*), lupine (*Lupinus* sp.), and a few annuals and other plants, all of which had been grazed almost to extinction by midsummer of that year. This vegetation occupied considerably less than one-tenth of the surface of the ground. The soil varies in depth from 2 to 25 feet or more, but in the exposed places is compacted and wholly lacking in litter cover; a surface horizon high in organic matter is wanting, and the surface is scarred by frequent gullies varying from a few inches to 2 to 5 feet in depth and width.

Much the same depletion exists between the trees in the more open parts of the broken patches of open-to-dense stands of aspen which extend from the steeper slopes to the bottoms and gentler slopes. Stubs of snowberry and other shrubs and occasional plants of coneflower and other species of inferior palatability to livestock make up the very limited undergrowth. The abundant leaf litter normally found on the ground on such sites was absent, and the surface soil was very compact. In places on the slopes where the more open stands of aspen give way to small thickets of sapling size, there is little undergrowth, owing to the dense shade and extreme competition for available soil moisture; but the aspen trees themselves are so numerous as to afford a good cover and have produced an abundant litter which is fairly intact. However, the area occupied by these aspen thickets is relatively small. Between the areas characterized by these more extreme conditions in the aspen type are those



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FIGURE 7.—The headwaters of one of the canyons which was flooded. The semibarren or barren spots on which the flood waters gathered are shown by the lighter places in the middle and foreground of the illustration. The darker portions in the foreground show the aspen groves in which practically all the undergrowth has been destroyed. Severe overgrazing has caused the destruction of the plant cover.



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FIGURE 8.—A near view of one of the slopes almost denuded of vegetation in the head of Ford Canyon. The destruction of the plant cover by overgrazing, the subsequent loss of the plant litter and layer of soil high in organic matter, and the continued trampling and packing of the soil set a perfect stage for torrential rain to gather and form the flood that swept through the canyons to the valley below.

conditions intermediate in tree-growth density and in depletion of undergrowth and loss of litter cover.

Conditions vary where the shrubs other than snowbrush predominate in the cover. Cover of any kind is very sparse or almost lacking on such places as sheep bedding grounds, ridge tops, and heavily used passageways from one drainage to another. In the more inaccessible places there are a few small, fairly dense patches of vegetation consisting chiefly of thickets of chokecherry or of sagebrush 2 to 4 feet in height, interspersed with clumps of snowbrush, with a fair undergrowth of herbaceous plants. However, the major portion of the cover is intermediate between these two extreme conditions and consists of an open stand of shrubs with a sparse stand of herbaceous undergrowth. The consequence is that in these places 70 to 95 percent of the ground between the shrubs is barren of vegetation, and there is but little litter cover.

The patches of snowbrush are more common on the drier, south-facing slopes where this species occurs in almost pure stands. This shrub generally forms a very dense growth. Except on a few places where there has been excessive trailing by the livestock in their movements from one drainage to another, or small burned areas, the snowbrush type provides a heavy, little-disturbed plant cover, having a mellow soil 1 to several feet in depth with a substantial litter of decaying plant material.

About one-fourth of the total area of the upper zone at the head of Ford Creek, consisting of not more than a thousand acres, is nearly denuded of vegetation and litter. The most densely covered areas amount to approximately one fourth to one third of the total area, and on the remainder the plant cover and surface soil are intermediate.

It was strikingly evident that the floods originated on the barren or nearly barren areas in the upper zone. The freshly eroded main flood channel in the bottom of each canyon extended continuously from the upper zone to the mouth. Most of the numerous gullies of all sizes which joined to form the main channel, when traced to their source, were found to originate on the areas where there was little or no vegetation (figs. 7 and 8). It was apparent that here the rain, falling on a surface little protected by vegetation and with a soil in poor condition to absorb moisture, instead of running off slowly or being absorbed by the soil, quickly collected in numerous streamlets which increased rapidly in size, velocity, and erosive power as they rushed down the slopes, cutting gullies as they swept along. In some instances gullies which started near the top slope in Ford Canyon, converged only a few hundred feet farther down to form channels nearly 20 feet deep. Even the gentler 3 to 5 degree slopes, when sparsely vegetated, had numerous gullies. The frequency, size, and distribution of the gullies on the parts denuded of vegetation show clearly that a large volume of water quickly accumulated on them.

Progressively outward from the barren areas, as the vegetation improved in density, gullies decreased in size and frequency with increase in vegetation, until in dense brush, or where the brush cover was well augmented by grasses and weeds or a substantial litter cover or both, there was no indication of torrential run-off. Under the

dense stands of snowbrush there were no gullies and the litter cover was barely disturbed, whereas only a short distance away in the overgrazed, scanty sagebrush stands, gullies were numerous and frequent, although less so than on the depleted slopes. Although practically no gullies originated in the aspen thickets, those formed on barren areas above continued on down in lessened size through the more open aspen stands.

The heads of all of the tributaries of Ford Canyon as well as the other canyons which were flooded presented essentially identical features. The only gully which extended down the slope through the oak zone into Ford Creek was found to originate in a small, gently sloping basin near the top of the broad ridge between Ford Canyon and Davis Canyon. The entire head of this tributary drainage has a cover of dense aspen, chokecherry, and other shrubs, except for an opening of not more than 12 acres in the basin. A corral for handling sheep has been built in this opening, and there the heavy grazing and trampling incident to the use of the corral has resulted in almost complete denudation. The evidence was clear that all the water necessary to erode a channel 15 to 20 feet in depth and width down the canyon slope in the oak zone, had accumulated on this denuded area.

The upper zone of Parrish Canyon watershed is smaller than that of Ford Canyon, approximately 700 acres. Also the relief of Parrish Canyon is less steep, the bottoms of its two principal forks are relatively broader than those of Ford Canyon, and there is a larger proportion of gently sloping canyon bottom and basinlike area. Although such conditions are less favorable for a quick accumulation of run-off, several mud flows approximately equal in size to those in Ford Canyon swept down Parrish Canyon in 1930. The sizable flood from the smaller, less steep Parrish Canyon watershed is accounted for by a relatively greater proportion of devegetated area in it as compared with that in Ford Canyon. Approximately one third of the area of the upper zone in Parrish Canyon was classified as extremely bare, as compared with one fourth of the area in Ford Canyon. This unfavorable condition was not ameliorated by the fact that the remaining area in upper Parrish Canyon is on an average in somewhat better condition as to soil and vegetation than that in Ford Canyon.

EVIDENCE SUPPORTING THE BENEFICIAL EFFECT OF PLANT COVER IN LESSENING FLOODS AND EROSION

The steep, well-vegetated intermediate side slopes of the canyons contributed practically no run-off to the floods which swept down the main-stream channels. Ford Canyon is typical. The slopes of this canyon from just above the mouth to within a mile or less of the summit of the Wasatch Range support a substantial cover of brush, principally oak brush and bigtooth maple (*Acer grandidentatum*), with patches of conifers (*Abies concolor* and *Pseudotsuga taxifolia*) and aspen on the north exposures. The conifer and aspen ordinarily have an admixture of brush including snowbrush, myrtle boxleaf (*Pachistima myrsinites*), and other species. The vegetation in this zone is normally too dense and the slopes are too steep to af-

ford ready grazing, and for that reason it is but little utilized by livestock and is not overgrazed except on occasional small openings probably originally caused by fire. The soil is fairly deep and rich, has a deep humus layer, and is overlain by several inches of litter consisting of shed leaves and other plant material in various stages of decomposition.

Evidence of any material contribution to the flood which swept down Ford Canyon from the dense vegetation of the oak zone, or of any run-off of consequence originating in this plant cover, was conspicuously lacking. The channel cut in the canyon by the flood was not appreciably deeper or wider at the lower end than it was where it entered the upper edge of the zone. No gullies originating on the adjacent steep, brush-covered slopes led into the flood channel. A single gully or wash that originated under different cover conditions on the upper edge of the canyon slope was continuous through the heavy vegetation but showed no evidence of receiving much if any additional water along its course. The litter and debris on the vegetated slopes extended down to the very edge of the main channel and showed no evidence of having been disturbed by running water during the torrential rainstorms, except in the small openings in the oak type previously referred to.

These openings bear witness to the fact that the rains were fully as heavy over the oak zone, as a whole, as on the parts of the watershed where the floods originated, and show the efficacy of plant cover in checking run-off and erosion. These small openings, practically barren of vegetation, were gullied during the storms in a manner similar to that evident on barren slopes both below and above the oak zone. Even though these openings are small—all that were examined were less than an acre in area—the heavy rain which fell on them had gathered quickly into streamlets which eroded gullies. However, on reaching the dense brush cover, this run-off was quickly dissipated over the slope, and the soil and other debris which had been picked up was dropped in the brush and litter. It seems very evident that in spite of torrential rainfall the floods in Ford Canyon did not gather in the heavily vegetated oak zone comprising about three-fourths of the area of the watershed, but came from the one-fourth of the drainage that lies farther up stream.

The oak-brush zone of three other canyons that were flooded in the Farmington-Centerville section all presented essentially the same picture as that in Ford Canyon. Their slopes differ some in gradient, but throughout this zone there was no evidence of heavy run-off or erosion except in the channel in the bottom of each of these canyons.

Further evidence of the effectiveness of a plant cover in checking erosion and run-off of flood proportions is found in Centerville Canyon, immediately south of Parrish Canyon. This drainage is similar to Parrish Canyon as to shape and topography but is slightly larger in area. Its watershed, in addition to having the heavy brush cover in the intermediate zone, is for the most part well vegetated in the upper zone. The town of Centerville has acquired approximately half of the land in the upper zone for watershed protection, and has arranged with the owners of the remainder of the land for restricted

grazing use. Private owners must not graze more livestock on the entire watershed than they would normally graze on their own land. Consequently the upper zone is not as depleted of vegetation as are the canyons farther north. The only injured spots are a few small favorite congregating places for cattle. Centerville Canyon did not produce a flood of any consequence. After each of the heavy storms the depth of flow in this canyon increased several feet, remaining so for several hours after the high floods in the canyons just to the north had passed. It is reasonable to suppose that the torrential rains extended over the watershed of this canyon. Small denuded patches on its slopes were gullied, having the same marks of torrential rainfall and run-off as the denuded areas on the watersheds farther north. Thus it seems evident that the better plant cover at the head of Centerville Canyon was effective in preventing a flood in this drainage.

FORMER CONDITION OF VEGETATION ON THE FLOOD-PRODUCING WATERSHEDS

It is evident that the areas which are now practically bare in both Ford and Parrish Canyons formerly supported a much heavier and considerably different vegetation. The bottoms and benches are potentially the most favorable sites for plant growth because of deep soil, accumulation of soil moisture from winter snow, and the protection that is afforded against drying winds in summer. Decadent remnants of shrubs indicate the former presence of a denser plant cover. Similar sites in other localities within the region of the floods, where practically the original plant cover has been maintained, support a heavy stand of grass, other herbs, and shrubs; occasional similar secluded places on watersheds adjacent to those which flooded now have a cover of such vegetation that occupies 40 to 60 percent of the surface of the ground and have a good cover of litter and a surface layer of soil high in organic matter.

The scanty plant cover on the nearly denuded areas, together with evidence from otherwise similar moderately or little grazed areas, indicates that the sagebrush and other shrub types, exclusive of the snowbrush, also formerly supported a much heavier stand of herbaceous plants. It is probable that the total vegetation in many places in these types formerly occupied 40 to 60 percent of the surface and afforded a substantial plant litter. This is in sharp contrast with the present cover, which in 1930 occupied sometimes less than 10 percent of the surface and which provided little or no plant litter.

The testimony of numerous nearby residents who have known the watersheds for many years substantiates the conclusion that the areas that now are practically denuded or have a sparse cover were formerly well vegetated.

Causes of depletion of the vegetation in the heads of the canyons which were flooded are convincing. It was apparent from conditions which existed when the area was examined in 1930 that the number of animals being grazed in both drainages was and for some years had been far in excess of what such range could be expected to support without severe overgrazing. Observations in July 1930, when

more than half of the grazing season remained, showed that the livestock on the area at that time had consumed most of the fairly choice vegetation and were subsisting on species normally little used on similar ranges when moderately grazed. According to information supplied by the owners of the lands, the head of Ford Canyon had been as heavily or more heavily stocked with sheep and a few cattle for not less than 10 years prior to 1930. Parrish Canyon has been grazed chiefly by cattle. Both the openings and the aspen patches in the bottoms and on the terraces of canyons are near the streams where livestock come to water and because of regular surface conditions, the shade afforded by the trees, and some forage growth each year, are favorite congregating, bedding, and grazing places for both sheep and cattle. Consequently these areas are extremely heavily grazed and trampled. The livestock are forced to utilize all but the most inaccessible areas because there is not sufficient forage on the more choice areas. The vegetation which remains is low in palatability and is that which commonly remains on or encroaches on overgrazed range (10). Several patches on the drier slopes have been swept by fire, and subsequent overgrazing has prevented the restoration of a normal plant cover. The more favorable sites are usually too moist to be burned; at least, there was no evidence at the time of examination of recent burns.

SUMMARY AND CONCLUSIONS

The results of the study covered in this publication afford geologic evidence of the value of plant cover in regulating surface run-off and controlling erosion. Recent serious floods in several canyons in the Centerville-Farmington section of northern Utah cut to extraordinary new depths in the previously undisturbed sands and gravels of the deltas and terraces of ancient Lake Bonneville. They also deposited quantities of debris and sediment on the former bottom of the old lake far in excess of the previous normal rate of deposition, and thus showed that the floods in these canyons were unprecedented, at least in modern times.

The floods followed rains which were torrential in character but by no means unique in volume or rapidity of fall. Their origin, as shown by excessive gully erosion, is traced primarily to relatively small areas, in the heads of canyons, which in recent times have been depleted of vegetation and denuded of plant litter, chiefly by overgrazing but to some extent by fire. The torrential rains did not cause run-off sufficiently concentrated to cause gulying on thickly vegetated parts of the watersheds, regardless of the steepness of slopes, although evidences of erosion on small barren areas in these parts indicate that the rainfall was approximately equal on both the well-vegetated parts and the depleted areas at the heads of the canyons.

It is concluded upon the evidence found on the watersheds that the floods which caused the recent radical departure from the normal post-Bonneville erosion and sedimentation in the canyons of the Centerville-Farmington area are directly attributable to the destruction, by overgrazing and fire, of the major portion of the vegetation and the concomitant loss of the plant litter and more porous topsoil on critical parts of the watersheds. There the soil and vegetation

which had become established long ago, and had been maintained through thousands of years, had been, until recently, the means of controlling run-off and preventing excessive erosion. On slopes the relation between vegetation and soil and run-off represents a delicate balance. This balance was broken when excessive grazing and fire so reduced the plant cover that the ground became relatively bare and the humus layer of soil was gradually eroded away. Furthermore, trampling had compacted the soil. On these denuded areas the run-off from cloudbursts was rapid, and the accumulated flood waters channeled deep gorges down the entire length of the canyons and spread debris in the valleys below. This variation from the long period of relative quiescence is convincing evidence that the recent violent floods represent a distinctly accelerated rate of run-off and erosion, traceable to depletion of the plant cover.

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